Preliminary Results of Single Pass Polarimetric SAR Interferometry

Yunjin Kim, Jakob van Zyl, and Anhua Chu
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109-8099

Tel: (818) 354-9500
Fax: (818) 353-5285
E-mail: ykim@radar-sci.jpl.nasa.gov

ABSTRACT

Unlike scalar interferometry, polarimetric interferometry provides the field cross correlation using various polarization responses. The main purpose of implementing polarimetric interferometry is to extract scattering medium information that may be difficult to obtain from scalar interferometry. Even though the formulation and initial demonstrations appear to be very promising, potential applications of polarimetric interferometry can only be verified by comparing polarimetric interferometry signatures with ground truth data. In order to accomplish this, the NASA/JPL TOPSAR system was modified to collect polarimetric interferometry data at C-band. During the 1998 deployment, several data sets were collected in the single pass polarimetric interferometry mode. In this paper, we discuss important issues related to polarimetric interferometry calibration. In addition, we briefly discuss the polarimetric interferometric signature using the TOPSAR data.

INTRODUCTION

S. R. Cloude and K. P. Papathanassiou first published the formulation of polarimetric interferometry [1] that can be mathematically expressed as the cross correlation of two polarimetric radar measurements as

$$\begin{bmatrix} \vec{S}_1 \\ \vec{S}_2 \end{bmatrix} \begin{bmatrix} \vec{S}_1^{\,+} & \vec{S}_2^{\,+} \end{bmatrix} = \begin{bmatrix} \vec{S}_1\vec{S}_1^{\,+} & \vec{S}_1\vec{S}_2^{\,+} \\ \vec{S}_1^{\,+}\vec{S}_2 & \vec{S}_2\vec{S}_2^{\,+} \end{bmatrix} \tag{1}$$

where the superscript symbol + denotes the transpose complex conjugate operator. Two antennas are separated in the cross track direction. The scattering vector $\vec{S}$ in the linear polarization basis is given by

$$\vec{S} = \begin{bmatrix} S_{hh} \\ S_{hv} \\ S_{vv} \end{bmatrix} \tag{2}$$

for the backscattering case where $S_{hv} = S_{vh}$. The diagonal terms are usual polarimetric SAR images and the off-diagonal terms provide the interferometric correlation relationship for various polarization responses.

IMPLEMENTATION AND CALIBRATION

In order to implement polarimetric interferometry at C-band, we combined the "ping-pong" TOPSAR and SAR polarimetry. That is, we modified the NASA/JPL AIRSAR system to collect the polarimetric data for both top and bottom antennas in the "ping-pong" sequence. Notice that the polarimetric interferometry pulse repetition frequency (PRF) is twice as high as the PRF of the usual polarimetric SAR. Therefore, the data-limited swath is only half of the usual swath. In the future, the four bit BFPQ (Block Floating Point Quantization) must be implemented to collect the data over the entire swath.

In order to derive the calibration technique, we consider three basic interferometric equations in the (s,c,h) coordinate. The definition of the coordinate is given by

s : unit vector parallel to projection of velocity vector into plane tangent to earth surface
c : unit vector in cross track direction making a right handed coordinate system
h : unit vector parallel to outward pointing normal to earth surface

Three scalar components (n_s, n_c, and n_h) of the unit look vector $\hat{n}$ satisfy equation (3), (4), and (5). Here, the unit vector is defined for each polarimetric interferometric pair.

$$n_s^2 + n_c^2 + n_h^2 = 1 \tag{3}$$

$$n_s = \frac{f_{DC}\lambda}{2v} \tag{4}$$

$$\frac{4\pi}{\lambda}\hat{n} \bullet \vec{B} = \phi \tag{5}$$

where f_{DC} is the Doppler centroid frequency, the vector $\vec{B}$ is the interferometric baseline, and the interferometric phase is denoted by ϕ. If all interferometric polarimetric data are processed using the same Doppler centroid, equation (5) is the only relevant equation for the calibration process. We propose the polarimetric interferometry calibration in two steps: the relative calibration between different polarization pairs and the usual interferometric calibration. Since the polarimetric interferometry signature can be relatively minute, it is necessary to perform the relative calibration precisely. Then, the usual interferometric calibration can be applied to one polarization data and subsequently all polarization combinations will be calibrated.

To illustrate our calibration method, we use three interferograms in the linear polarization basis: ϕ_{hh}, ϕ_{vv} and ϕ_{hv}. The differential interferograms shown in equations (6), (7) and (8) have necessary information for relative polarization calibration. Mathematically,

$$\begin{aligned}\Delta_{hhvv}(r,a) &= \phi_{hh}(r,a) - \phi_{vv}(r,a)\\ &= C_{hhvv} + \beta_{hhvv}(r,a) + S_{hhvv}(r,a) + M_{hhvv}(r,a) + n_{hhvv}(r,a)\end{aligned} \tag{6}$$

$$\begin{aligned}\Delta_{hhhv}(r,a) &= \phi_{hh}(r,a) - \phi_{hv}(r,a)\\ &= C_{hhhv} + \beta_{hhhv}(r,a) + S_{hhhv}(r,a) + M_{hhhv}(r,a) + n_{hhhv}(r,a)\end{aligned} \tag{7}$$

$$\begin{aligned}\Delta_{hvvv}(r,a) &= \phi_{hv}(r,a) - \phi_{vv}(r,a)\\ &= C_{hvvv} + \beta_{hvvv}(r,a) + S_{hvvv}(r,a) + M_{hvvv}(r,a) + n_{hvvv}(r,a)\end{aligned} \tag{8}$$

where C is the constant phase (radar channel differential phase), β is the phase due to baseline vector difference, S is the phase due to the different scattering mechanism, M is the multi-path phase, and n represents the thermal noise difference. If we average Δ in the along track direction for the flat calibration site, the scattering related phase difference S and the radar noise term n will be significantly reduced. That is, $\langle S \rangle_a \approx \langle n \rangle_a \approx 0$.

The resulting azimuth averaged phases are shown in Fig. 1 and Fig. 2. In Fig. 1, the HH and VV phase difference includes the constant differential phase, the baseline difference phase, and the multi-path phase. Especially, the phase variation in the range direction is due to the baseline difference and the multi-path effect.

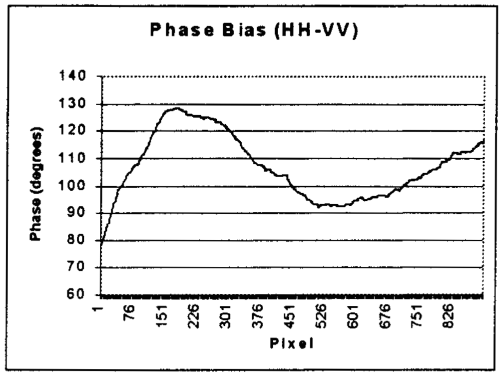

Fig. 1. Phase bias calculated by averaging the interferogram difference (HH-VV) in the azimuth direction.

Due to the reciprocity relation, the baseline difference phase and the multi-path effect disappear in the HV and VH interferogram difference as shown in Fig. 2.

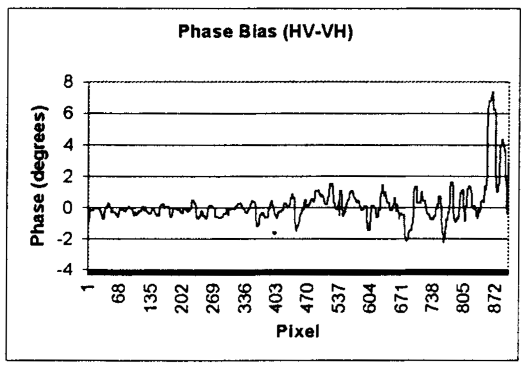

Fig. 2. Phase bias calculated by averaging the interferogram difference (HH-VV) in the azimuth direction.

POLARIMETRIC INTERFEROMETRIC SIGNATURE

Recently, several successful demonstrations of estimating the tree height by using the amount of decorrelation were reported [2,3]. However, the exact relationship depends on the tree scattering structure. It is well known that the co-polarized phase difference can be used for classification since it comes from the scattering center displacement; however, for the forest area, the co-polarized phase appears to be random since the phase center displacement may be larger than the wavelength. This problem can be remedied if polarimetric interferometry is implemented and the interferometric phase difference is above the phase noise level. That is, polarimetric interferometry unwraps the polarimetric phase difference for the forest area. In order to show the feasibility of using various applications such as classification and the tree height estimation, we studied the polarimetric interferometric data collected by the NASA/JPL AIRSAR. As shown in Fig. 3, the polarization dependence interferometric phase can be observed. This phase information is related to the phase center location. With the associated correlation amplitude, one may be able to characterize the scattering medium.

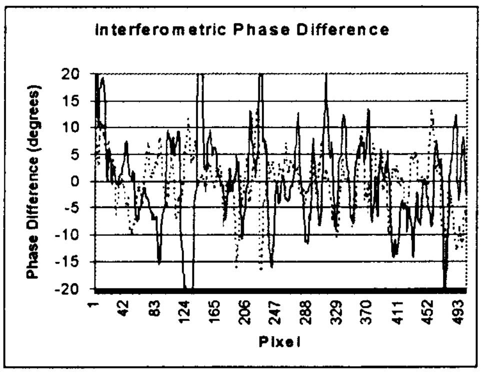

Fig. 3. Difference in observed interferometric phase measured at C-band by using the NASA/JPL AIRSAR system. The dashed line represents the difference using the HH and VV combinations (HH-VV), and the solid line represents the difference when using the VV and HV polarization combinations (VV-HV). The phase difference of 10 degrees is approximately 2 meters in the height difference.

CONCLUSIONS

The NASA/JPL AIRSAR system was upgraded to collect polarimetric interferometric data. The preliminary analysis showed that the interferometric signature varies with the radar polarization. In order to verify the usefulness of polarimetric interferometry, it is necessary to understand the associated scattering signatures by comparing them with the ground truth.

ACKNOWLEDGMENT

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

REFERENCES

[1] S. R. Cloude and K. P. Papathanassiou, "Polarimetric SAR Interferometry," *IEEE Trans. Geosci. Remote Sens.*, **GE-36**, 1551-1565, 1998.

[2] E. Rodriguez, T. R. Michel, and D. J. Harding, "Interferometric measurement of canopy height characteristics for coniferous forests," submitted for publication.

[3] R. N. Treuhaft and P. R. Siqueira, "The vertical structure of vegetated land surfaces from interferometric and polarimetric radar," submitted to Radio Science.